Ontario

Ministry of Transportation
Highway Standards Branch Report

Examination of Cores from Tall Wall Median Barrier, Highway 401, Trenton Area - The Ministry of Transportation of Ontario

MERO-024

Technical Report Documentation Page

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Abstract	Slipformed tall wall median barrier in the Ministry's Eastern Region showed significant deterioration after approximately 10 years in service. The Region removed cores from the wall and requested that Materials Engineering and Research Office (MERO) identify the cause of the premature deterioration. In the Ministry's Downsview laboratories the strength and air void parameters of the cores were determined, and petrographic analysis was carried out. Inconsistent strengths indicated that although the mix was capable of attaining a good strength there was a high degree of variability. The air void system in the concrete was adequate, meeting current specification requirements. The cores showed no signs of durability problems that can develop during the life of the concrete, such as distress related to freezing action or reactivity of aggregates. Instead the cores exhibited distress related to actions at the time of construction, showing evidence of poor consolidation, inadequate mixing of the concrete and the occurrence of cracking while the concrete was in a very young state. Cracks were also present consistent with tearing of concrete by the slipforming machine during placement of the concrete. The causes of the current deterioration are defects that were created at the time of construction and magnified during the service life by natural actions of water movement, saturation, leaching and frost. Since the wall was constructed, the level of expertise in the industry with respect to placement of slipformed barrier walls has improved, and changes have been made in the ministry's specifications. Improved quality of construction has resulted, with corresponding expectations for improved durability over time.
Key Words	Concrete barrier, concrete in tall wall, concrete durability, concrete construction practices, construction defects, laboratory testing of concrete
Distribution	Unrestricted technical audience

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Executive Summary

A slipformed tall wall in the Trenton area of Ontario, in the Ministry's Eastern Region, showed significant deterioration after approximately 10 years in service. The Region, while carrying out repairs to the wall, removed a number of cores and forwarded them to MERO with a request to identify causes of this premature deterioration.

In the Ministry's Downsview laboratories the compressive strength and air void system parameters of the cores were determined, and petrographic analysis was carried out. The cores had inconsistent strengths indicating that although the mix itself was capable of attaining a good strength it exhibited a high degree of variability. The air void system in the concrete was adequate to meet the ministry's current specification requirements. The cores show no indication of typical durability problems that would develop during the life of the concrete, such as distress related to freezing and thawing or to reactivity of aggregates. Instead the cores exhibited distress that would have occurred during the actual placement of the concrete; there is evidence of lack of proper consolidation, inadequate mixing of the concrete and the occurrence of cracking while the concrete was in a very young state. Some cracks are consistent with tearing of concrete by the slipforming machine during placement of the concrete.

The causes of the current deterioration are the defects that were created at the time of construction and were magnified during the service life by natural actions of water movement, saturation, leaching and frost. These actions made the concealed cracks visible, widened the surface cracks, and leached lime compounds to the surface creating distinctive staining.

Since the wall was constructed, the level of expertise in the industry with respect to placement of slipformed barrier walls has improved considerably. Changes in MTO specifications have helped to ensure that acceptance is based on samples from the wall, rather than cylinders, thereby providing a better indication of the quality of the end product. At the current time, cores are removed from the wall for evaluation of air void parameters; in future, cores will also be used for strength determination.

For potential future application, the Concrete Section is evaluating the use of the ultrasonic pulse velocity technique for detection of internal voids, cracks and poorly compacted areas. This may be useful in identifying and quantifying future areas for repair. Specialty admixtures that would make concrete more workable at low slump and reduce adherence to the form, and therefore the tendency for tearing cracking, are also being explored with industry.

Examination of Cores from Deteriorated Tall Wall Median Barrier Highway 401, Trenton Area

In the early nineties the Eastern Region constructed a median barrier in the Trenton area that began showing signs of deterioration after about 10 years in service. To restore the wall Eastern Region decided to replace the worst sections of it and extract cores from surrounding areas in order to determine the cause of the wall's poor durability. The cores were extracted from the wall in November 2002 and forwarded to the Concrete Section of Materials Engineering and Research Office in Downsview for analysis.

The wall was constructed in July and August 1992 under Contract 91-81 by Dufferin Construction and was one of the first slipformed tall walls built in Ontario. It extended along the Highway 401 median, from Highway 33 easterly for 8.5 km to Aikens Road. Compressive strength of the concrete was specified to be 35 MPa. Concrete was supplied by Peterborough – Port Hope Ready Mix, a unit of Dufferin Construction Concrete Group and by Permanent Concrete a division of Lafarge Canada Inc. The Dufferin plant was a temporary one and was located in the Longs Quarry, owned by Wimpey Minerals, the source of the coarse aggregate on this contract. The fine aggregate was supplied by Pinewood Aggregates in Westwood. The contractor used concrete mix with 385 kg/m^3 of Type 10 cement supplied by St. Lawrence Cement Co.; no slag was used. Water/cement ratio was about 0.3 and slump was maintained between 5 and 25mm. Water reducing and air entraining admixtures were supplied by Grace Canada Inc. Water reducing admixture WRDA 20 was used at a dosage of 220 mL/100 kg of cement; air entraining admixture was Daravair.

Average compressive strength reported on the contract was 39.8 MPa with individual test results ranging from 31.7 to 44.3 MPa. Two out of a total of sixty two results were below 35 MPa. Inspection reports from this contract mention problems with concrete cylinders. Some of them were badly made and had to be cut to a ratio of 1:1.8 in order to allow compressive strength testing. The reports also describe tearing of concrete by the slipforming operation in the upper part of an asymmetrical wall. The tearing problem was reported to be resolved.

In 2002, six sections of the tall wall were removed and replaced by precast segments under Contract 2002-4314. At that time twelve cores were obtained from the deteriorated sections at the following locations, as identified by the Region:

Location No.4 - Hwy 401; 3.5 km east of Hilaire Road, core numbers 11 and 12,
Location No.5 - Hwy 401; 3.6 km east of Hilaire Road, core numbers 9 and 10,
Location No.6 - Hwy 401; 3.7 km east of Hilaire Road, core number 8,
Location No.7 - Hwy 401; 3.9 km east of Hilaire Road, core numbers 6 and 7,
Location No.9 - Hwy 401; 4.1 km east of Hilaire Road, core numbers 4 and 5,
Location No.10 - Hwy 401; 4.2 km east of Hilaire Road, core numbers 1,2 and 3.

Location Nos.1, 2, 3, 8 and 11 had originally been scheduled for removal and replacement but were not included in the repair contract and no cores were extracted from these locations.

From the twelve cores the Concrete Section selected cores for compressive strength and air void system and Soils and Aggregates Section selected cores for petrographic examination. Cores 1, 3 and 12 were tested for compressive strength and core 9 for air void system. Chris Rogers, Manager of the Soils and Aggregates Section, petrographically examined cores 9 and 10 and end fragments of cores 1, 3 and 12 that were saved from compressive strength testing. His petrographic report is provided as Appendix A.

The individual core descriptions and test results including the general findings of the petrographic analysis are provided below.

LOCATION 4, Cores 11 and 12

Core 11 was extracted from the top of the wall. The core came in two halves probably a result of extensive cracking in that area. More severe cracking is present in the top half (Figure 1). The cracks are normal to the top surface, are very wide, ranging in width from 2 to 5 mm, and pass around rather than through aggregate particles. At places the cracks are as little as 10mm apart. The cracks end about 5 mm from the top surface of the core. There they are closed by a layer of paste that effectively masks the condition of concrete underneath. The fact that cracks run around the aggregate and that the concrete was consolidated at the top and the cracks closed indicate that they formed when the concrete was plastic. The presence of the layer of paste applied when the concrete was fresh would indicate there was some awareness of a problem at the time the concrete was placed

The lower half of the core 11 came from a lower location in the wall and contains fewer cracks than the top half. The cracks in this portion run in one direction and appear to be tearing cracks. The concrete contains paste-rich areas with no coarse aggregate indicating inadequate mixing of the concrete or perhaps segregation caused by vibration or placement operations (Figure 2).

Core 12 was sampled from the mid height of the wall (Figure 3). The concrete appeared uniform and had a good strength of 49.9 MPa . On petrographic analysis a surface crack was found on this core. It was judged to be a drying shrinkage crack. A more detailed description of this crack can be found in the Appendix A.

LOCATION 5, Cores 9 and 10

Core 9 was cut horizontally from the upper third of the barrier wall. It is uncracked but has extensive paste-rich areas with no coarse aggregate; up to one third of the core contains this poorly mixed/segregated material (Figure 4).

Core 10 was cut vertically from the top of the wall. This core also contains paste-rich areas

with no coarse aggregate (Figure 5). It has one wide crack on the inside of the core that ends about 15 mm from the top surface of the core where a layer of visibly different colour concrete tops the core (Figures 6 and 7). Again, as in core 11, the crack runs around the aggregate and would have been formed while the concrete was plastic.

Cores 9 and 10 have noticeably different colour/shade of paste (Figure 8). This colour difference could have been the result of different cements or concrete mix designs being used. Higher water content of an otherwise identical mix will also result in a lighter coloured paste. As water content increases the paste contains more pores (has lower density) and that makes it appear lighter. Chris Rogers verified in his petrographic report that the colour difference is due to water content difference (see appendix A) and supports this by his observation that the lighter paste was also softer.

LOCATION 6, Core 8

Core 8 was taken horizontally from the side of the wall. It is uncracked and the concrete is uniform. This core contains a number of voids approximately 10 mm in diameter and larger (Figure 9). Such voids were not observed on the other cores obtained from this wall.

LOCATION 7, Cores 6 and 7

Core 6 was removed vertically from the top of the wall. This core contains a paste-rich area with no coarse aggregate indicating poor mixing (Figure 10). It is cracked; the cracks run around the aggregate, are discontinuous, near vertical and angled in one direction (Figure 11). The direction of the cracks and the fact that it formed early indicate that it is a tearing crack created during slipforming.

Core 7 was sampled from the mid height of the wall. The concrete is uniformly mixed and contains smaller tearing cracks that are discontinuous, similar to those found in the core 6 (Figure12).

LOCATION 9, Cores 4 and 5

Core 4 was obtained from the mid-height of the wall. The concrete appears well mixed and contains no cracks (Figure 13). As indicated by an analysis of the air void system parameters of the concrete, core No.4 had a good air void system with total air content of 4.8 % and spacing factor of 0.1394 mm. But it was noted that some areas of the polished core surface contained noticeably more air than other areas of the core.

Core number 5 was cut from the haunch area of the wall. The concrete is uniform with no paste-rich areas and no cracks (Figure 14). However, the paste in the core 5 has visibly lighter colour compared to core No.4 (Figure 15). This colour difference is similar to that found in the cores 9 and 10 sampled from the location 5 and is probably also caused by the water content difference in the two cores.

LOCATION 10, Cores 1, 2 and 3

Core 1 was removed from the top of the wall, vertically. This core was tested for compressive strength. The concrete was uniform, contained no cracks (Figure 16) and had a relatively high strength of 48.5 MPa.

Core 2 was cut horizontally from the middle portion of the wall. The concrete is uniform. It contains one crack that runs from the surface inward to a depth of about 75 mm and was probably formed in the plastic state as it runs around the aggregate and appears to have been closed by hand finishing at the surface as the crack is wider inside than it appears on the surface (Figure 17).

Core 3 was obtained from the bottom of the wall at the haunch area. The core, when tested for compressive strength, had a strength of only 29.8 MPa. This core contained a paste-rich area of significant size with no coarse aggregate (Figures 18 and 19). No cracks were present.

COARSE AND FINE AGGREGATE

The coarse aggregate was supplied by Longs Quarry, Wimpey Minerals. One of the five cores (the core 3) contained "reaction rims with associated trace deposits of apparent alkali-silica gel and ettringite filling air voids in the fragment taken from the bottom of the core ", according to the petrographic report. Testing of the coarse aggregate in 1992 demonstrated that it was well within the requirements for alkali silica reactivity. Although the ministry's requirements have been tightened since 1992, making the coarse aggregate marginally reactive relative to today's standards, it would still be insufficient to be a cause of the cracking and damage in this barrier wall (see Appendix A).

Fine aggregate from Pinewood Aggregates in Westwood was judged to be sound and suitable for use in concrete.

SUMMARY

Generally, the concrete was strong with good coarse and fine aggregate bond and it was well proportioned.

The air void system obtained on core 4 was good, although distribution was not uniform throughout the examined surface. Air entrainment in cores 1, 3, 9, 10 and 12 was judged to be good, with about 4-5 % air, when examined petrographically.

Compressive strength was good, just under 50 MPa, in the cores 1 and 12. However, the core 3 only measured 29.8 MPa, probably as a result of poorly mixed concrete evident in that core.

Poorly mixed or segregated concrete was evident in 5 of the 12 cores (42%), cores 3, 6, 9, 10 and 11. These cores contained paste-rich areas with little or no coarse aggregate.

Cracks were found in cores obtained from the top (cores 6, 10, and 11) and mid-height (cores 2, 7, and 12) of the wall. The cracks in the cores from mid-height were less severe than those found in the cores from the top of the wall. These cracks appeared to have been initiated when the concrete was in the plastic stage, by tearing of concrete during the slipforming operation. Some of the cracks although severe were less obvious at the wall surface, because there they had been closed by hand finishing (core 11) or in core 10, concealed by a layer of concrete; this surface work would tend to indicate the problem was noted at the time of construction.

Shallow drying shrinkage cracks were observed in the patching layer found at the top of the core 10. Core 12 also contained a small drying shrinkage crack.

Staining of the wall reported by the Eastern Region and shown in Figure 20, but not present on the individual cores, was likely caused by leaching of lime compounds and subsequent deposition on the surface of concrete. This typically occurs in poorly consolidated or cracked concrete. Also, high alkali cements often cause this kind of staining adjacent to cracks. The cement used did have relatively high alkali content.

There were no signs of deterioration of the aggregate due to chemical reactions or freezing and thawing, except in the core 3. The fine and coarse aggregates were not sufficiently reactive or otherwise objectionable to contribute in a significant way to the deterioration of this concrete.

CONCLUSIONS AND FUTURE WORK

Deficiencies found in the cores extracted from the tall wall, in the Highway 401 median, at the six locations from 3.5 km to 4.2 km east of Hilaire Road, can be traced to problems encountered during construction. There is evidence of tearing cracks, poor consolidation and concrete that was either poorly mixed or, less likely, segregated during placement and vibration. The concrete was capable of reaching the specified strength but due to mixing inadequacy and placement problems did not consistently reach that strength and exhibited a very high degree of variability.

No defects, such as freeze thaw distress or alkali silica reactivity, that would develop while the concrete was in service were identified.

The observed problems can be minimized by adhering to the current specification, which in the near future will be modified to require removal of cores for evaluation of compressive strength of the finished product. This should provide a more accurate assessment of the strength and quality of the end product, compared to determination of strength based on

cylinders.

The Concrete Section is also investigating new approaches to ensuring quality of concrete in the wall. Non-destructive techniques, such as ultrasonic pulse velocity and impact echo, are being evaluated to identify areas of poorly consolidated/ cracked concrete in the interior of the concrete. This could possibly in future allow early detection of the presence of internal cracks and voids, and may also be helpful in identifying wall areas requiring repair.

The Concrete Section is also planning to evaluate non-standard water reducers formulated to efficiently disperse water in low slump concrete and reduce surface tension at the form surface to prevent sticking of concrete to the form and reduce the tearing cracking.

APPENDIX A

Petrographic Analysis by Chris Rogers

I examined cores 9 and 10 from this contract. I also examined the end fragments of cores 1, 3 and 12 saved from compressive strength testing.

Generally the concrete was strong with good coarse and fine aggregate bond and generally well proportioned. There were areas of severe segregation of coarse aggregate in both cores 9 and 10.

The coarse aggregate was a crushed limestone of the Bobcaygeon Formation and showed all the chacteristics of having come from the Longs quarry (BO8-O15) near Belleville. This is the source of stone shown on the two mix designs dated 92-06-26. The material was a medium to coarse crystalline limestone from the second bench of the quarry. The upper bench is a shaley limestone and had given problems in the 1980's with black shaley pop outs on flat work. There were no signs of deterioration of the stone due to chemical reactions or freezing and thawing except in core 3. Core 3 showed reaction rims with associated trace deposits of apparent alkali-silica gel and ettringite filling air voids in the fragment taken from the bottom of the core. There was insufficient material to sample for confirmatory testing. I should note that we conducted testing in June and July 1992 in our lab of this stone and obtained test data which showed it met all specification requirements including those for alkali-silica reactivity. The accelerated mortar bar expansion (CSA A23.2-25A) was 0.100% at 14 days which was well within our requirement at that time. We have since reduced the requirement to 0.100%. Values in excess of that require further long term testing in concrete prism tests (A23.2-14A). I conclude that the stone may have been marginally reactive but insufficient to be a cause of the cracking and damage in the barrier wall.

The fine aggregate was a natural sand containing 70% rocks and minerals of the Gull River and Bobcaygeon Formations and 30% quartz, feldspar and associated minerals from Precambrian rocks. The material was consistent with having come from the Pinewood Pit (P09-104) to the east of Peterborough. The Pinewood pit is shown as the source of fine

aggregate on the mixture design. It may be that a source of the trace amounts of alkali-silica gel found in core 3 was cherty limestone in the 2-5mm particle size of this material. The material was judged to be sound and suitable for use in concrete.

The cement paste was sub-translucent under the microscope and a light grey to off white colour and showed marked differences within core 10. In core 10 the interior of the concrete was an off white colour and the paste had a relatively soft scratch. The surface 15 mm was of a light grey colour and had a harder scratch. I conclude that the lighter coloured paste was of higher water / cement ratio. Core 9 was a light grey colour throughout.

The concrete was well air entrained with an estimated 4-5% air void content in all cores. It should be noted that the air voids were generally small (even for air entrainment voids) and rarely contained any filling or lining material except in parts of core 3.

Core 9 was uncracked. Core 10 contained a 1 to 4 mm wide crack about 160 mm long normal to the outer surface. The crack was in the area of off white paste and ran around aggregate particles rather than through them, indicating that cracking occurred at a very early age. The crack was unlined with secondary minerals. The crack ended about 15 mm below the surface at the layer of light grey paste. The light grey paste had very fine fractures which were characteristic of drying shrinkage. These cracks were estimated to be less than 0.1 mm wide and penetrated from the surface about 10 mm. There were stains on either side of the crack at the concrete surface. Core 12 also had a surface crack normal to the surface. It was not possible to estimate thickness since the concrete separated on the crack surface during cutting in the laboratory. The crack walls were dirty and weathered. The crack generally ran around rather than through coarse aggregate particles. This crack was also judged to be due to drying shrinkage.

I conclude that the large crack found in core 10 was probably formed in the concrete at the time of placement and is a crack caused by tearing of the concrete by the slip-form machine. The finishers, who were working the surface after the machine, closed the crack near the surface (upper 10- 15 mm) but were unable to consolidate the concrete below this level. The surface subsequently cracked due to shrinkage. The movement of water within the concrete and evaporation at the surface is depositing trace amounts of dissolved substances within the water at the surface resulting in the objectionable staining. I should note that the mixture design called for the use of St Lawrence Type 10 cement which has about 1 % alkalis (the highest in Ontario at that time). High alkali cements often cause this kind of staining adjacent to cracks.

The aggregates are not sufficiently reactive or objectionable to contribute in a significant way to the deterioration of this concrete.

Figure 1

Location 4, Core 11

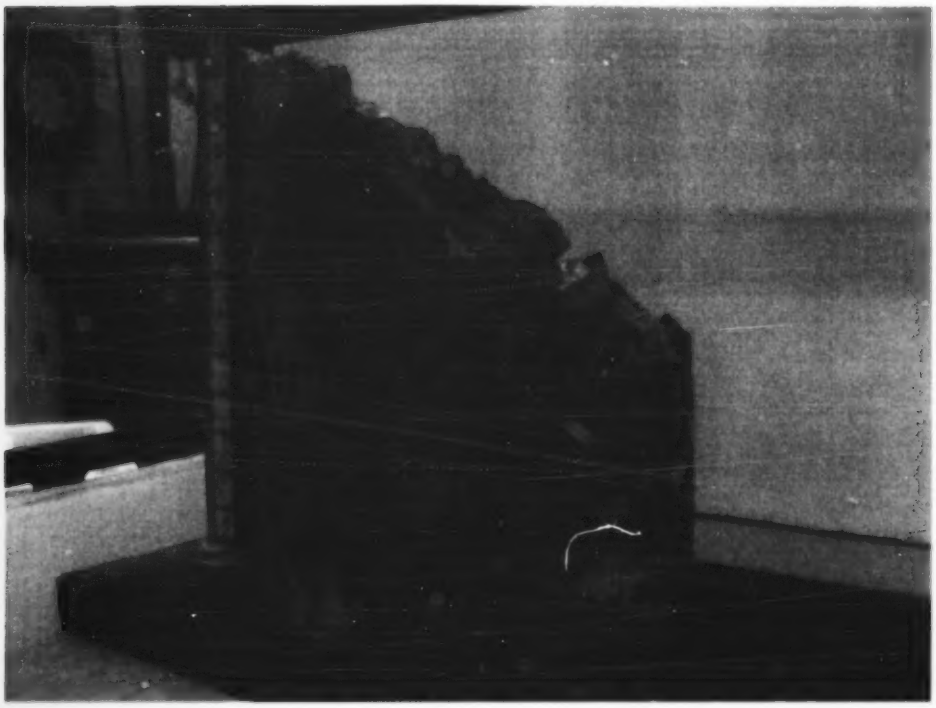

Figure 2

Location 4, Core 11, second half

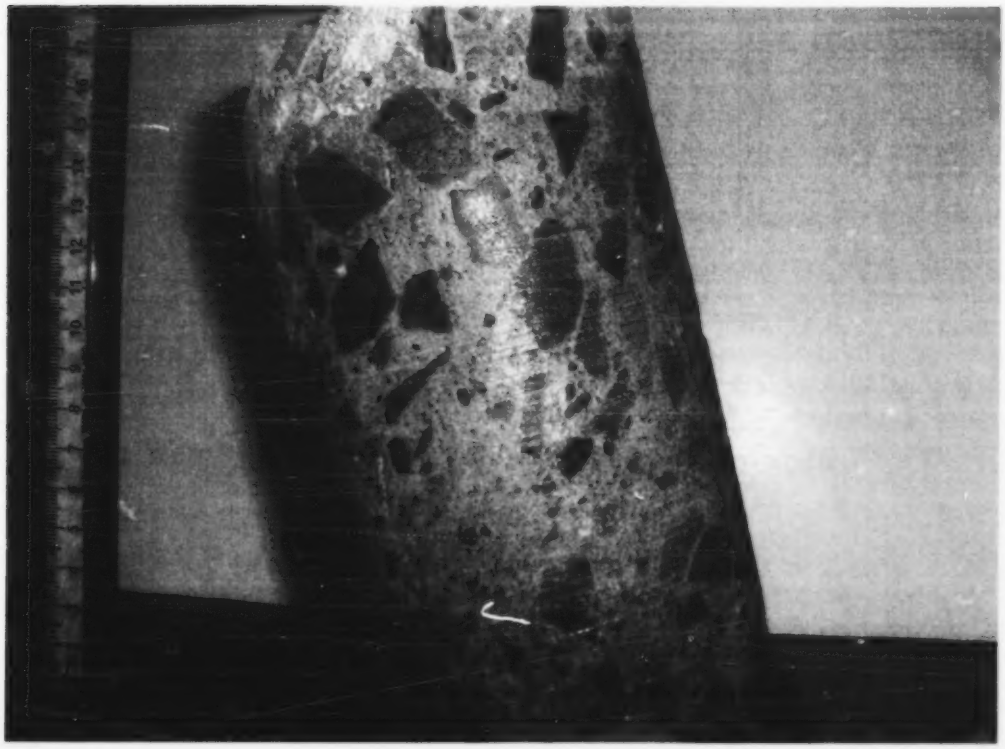

Figure 3

Location 4, Core 12

Figure 4

Location 5, Core 9

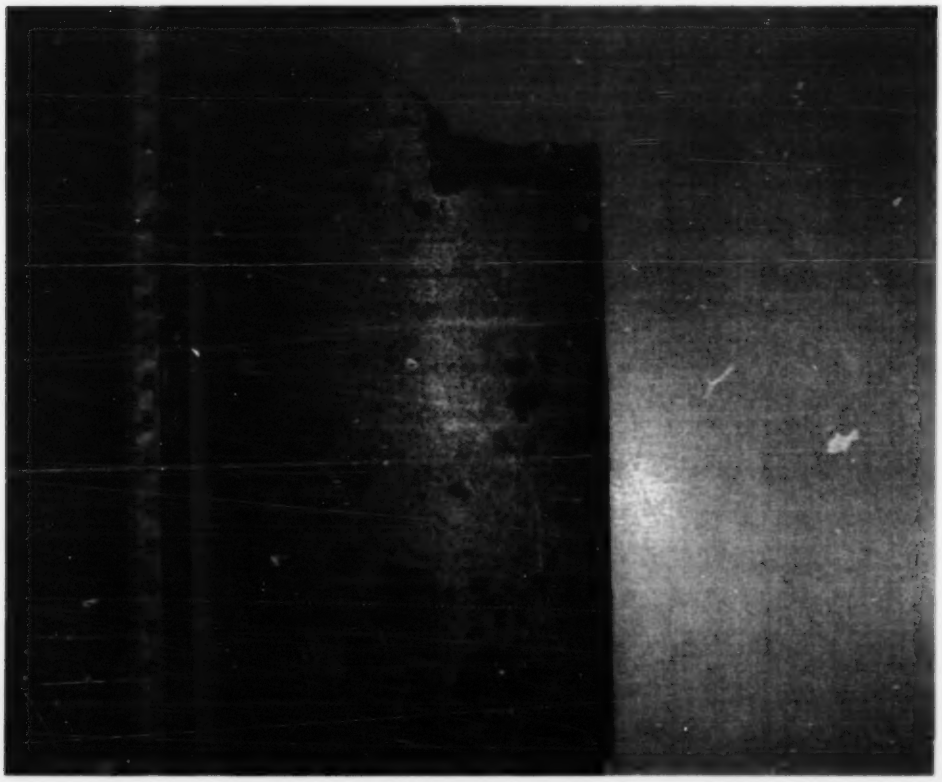

Figure 5

Location 5, Core 9

Figure 6

Location 5, Core 10

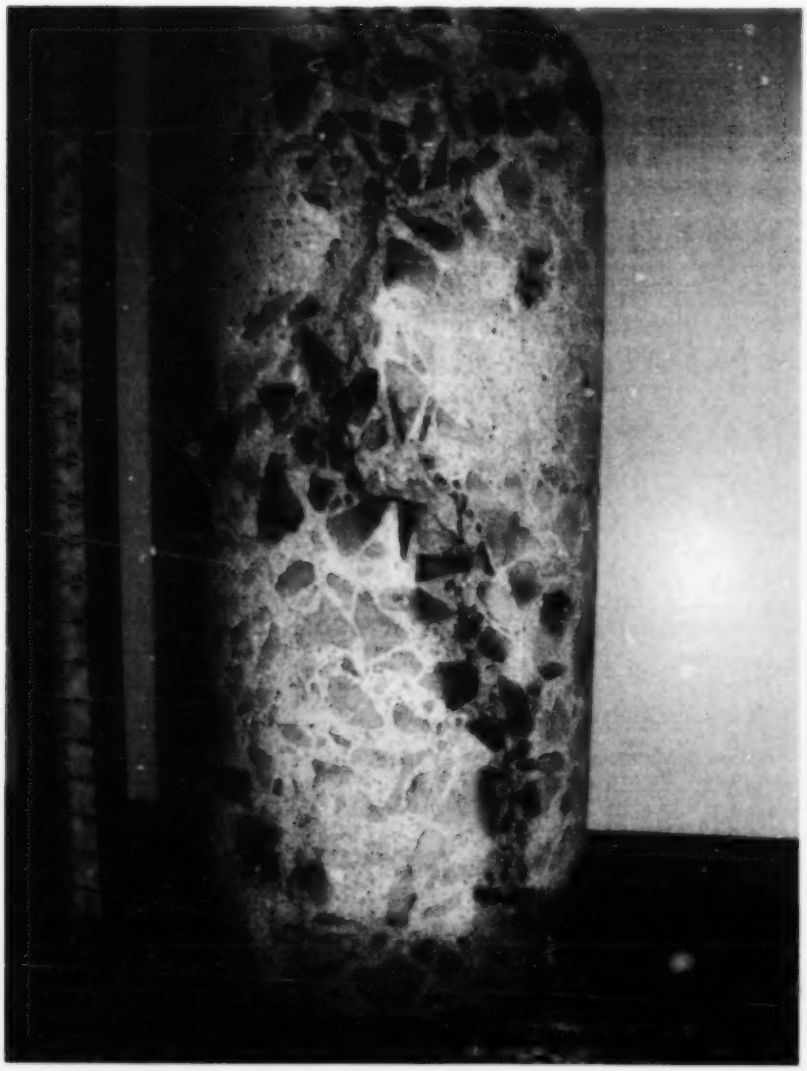

Figure 7

Location 5, Core 10, Layer of Different Concrete

Figure 8

Location 5, Cores 9 and 10, Close-up

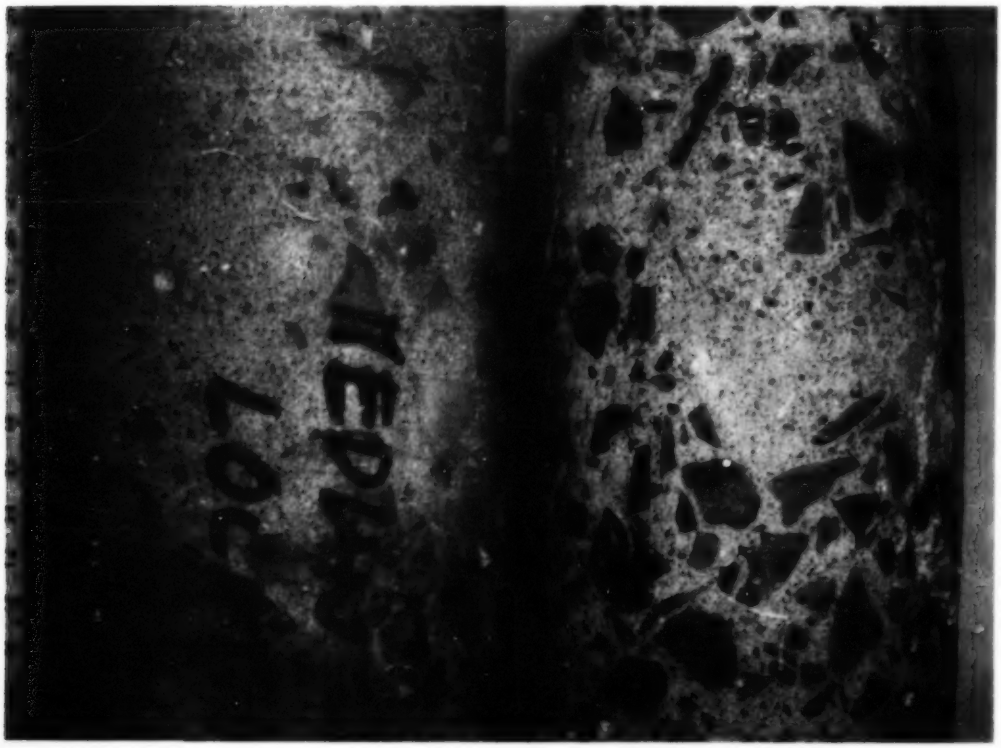

Figure 9

Location 6, Core 8

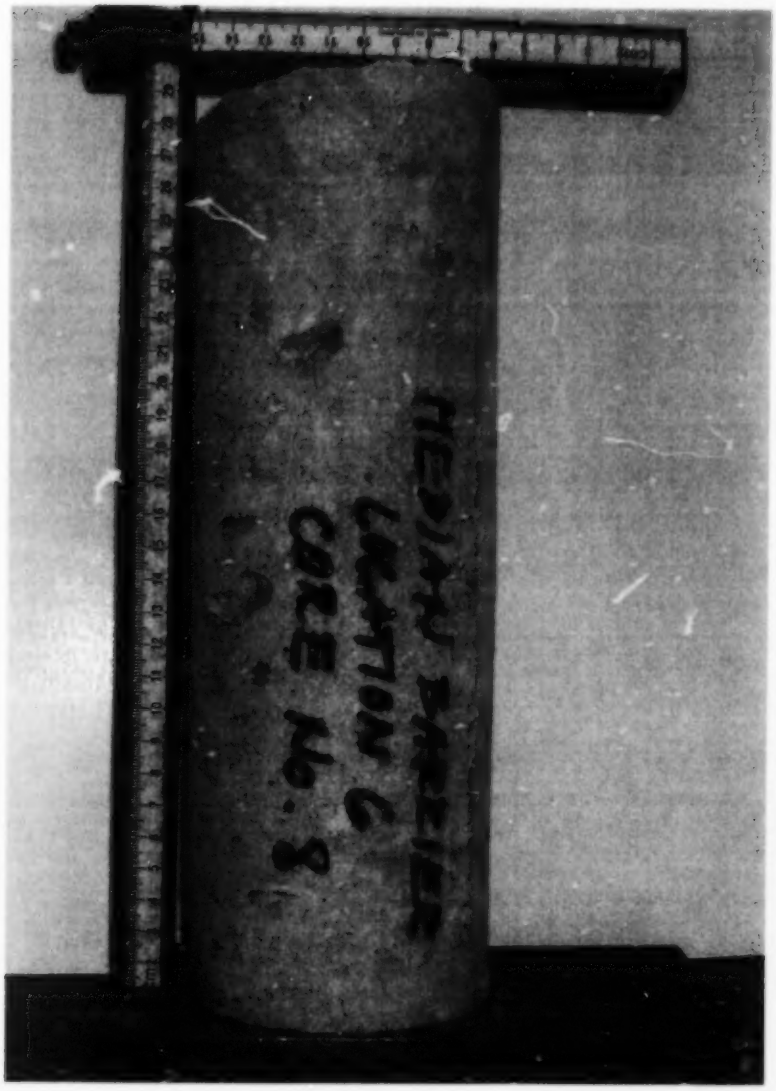

Figure 10

Location 7, Core 6, Paste-rich Area

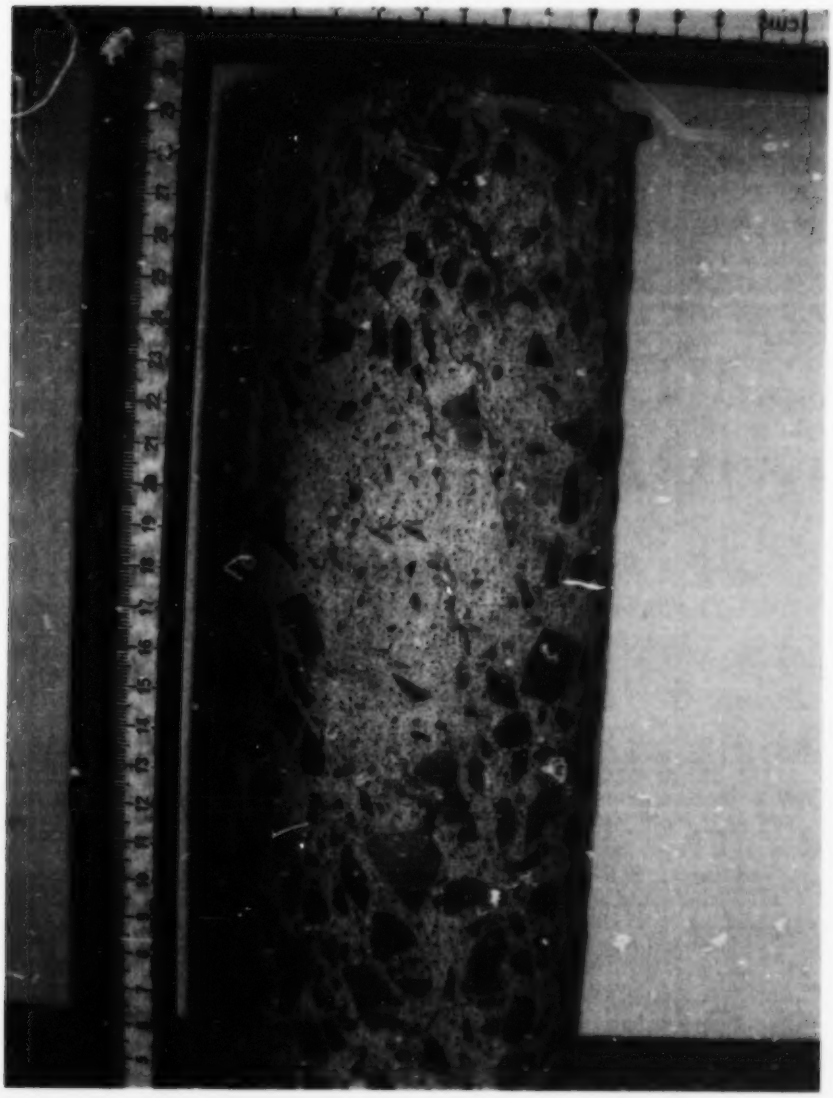

Figure 11

Location 7, Core 6, Cracks

Figure 12

Location 7, Core 7

Figure 13

Location 9, Core 4

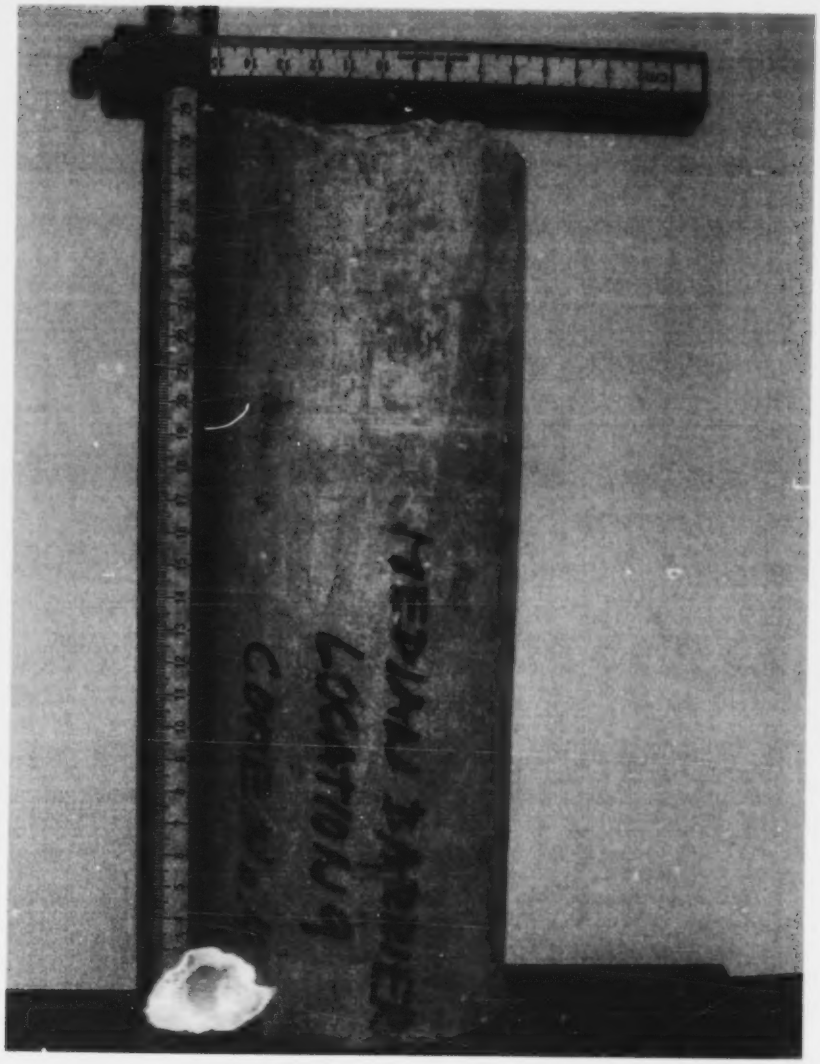

Figure 14

Location 9, Core 5

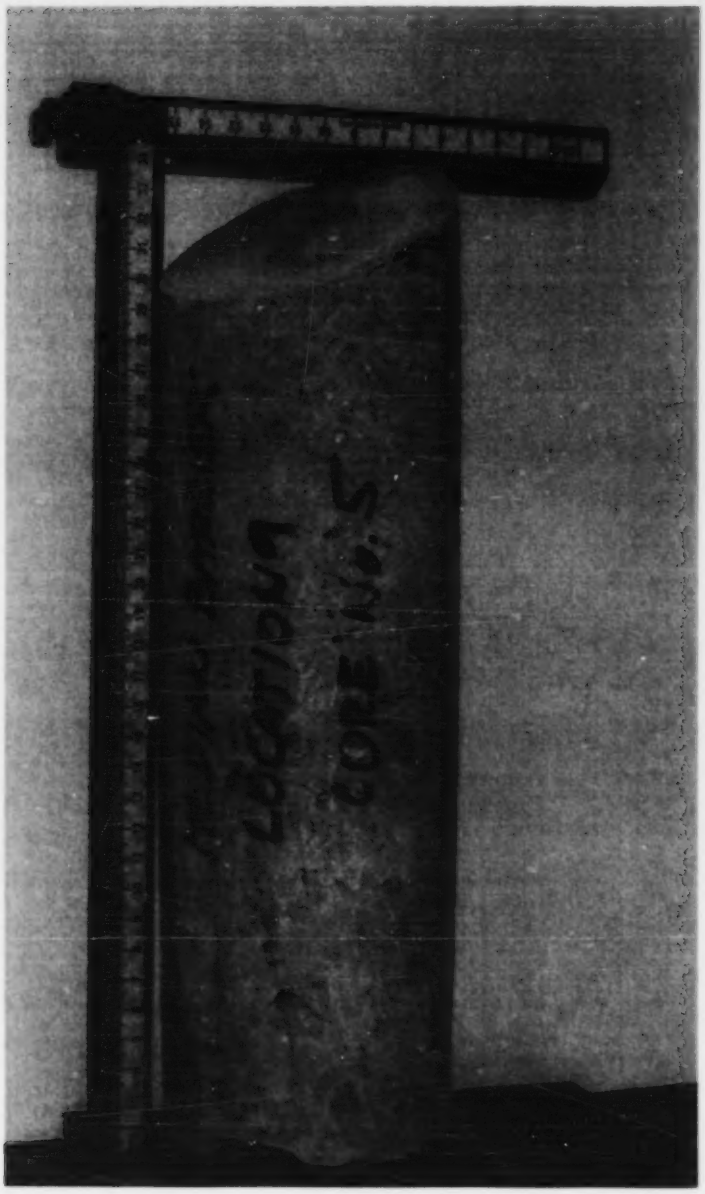

Figure 15

Location 9, Cores 4 and 5, Close-up

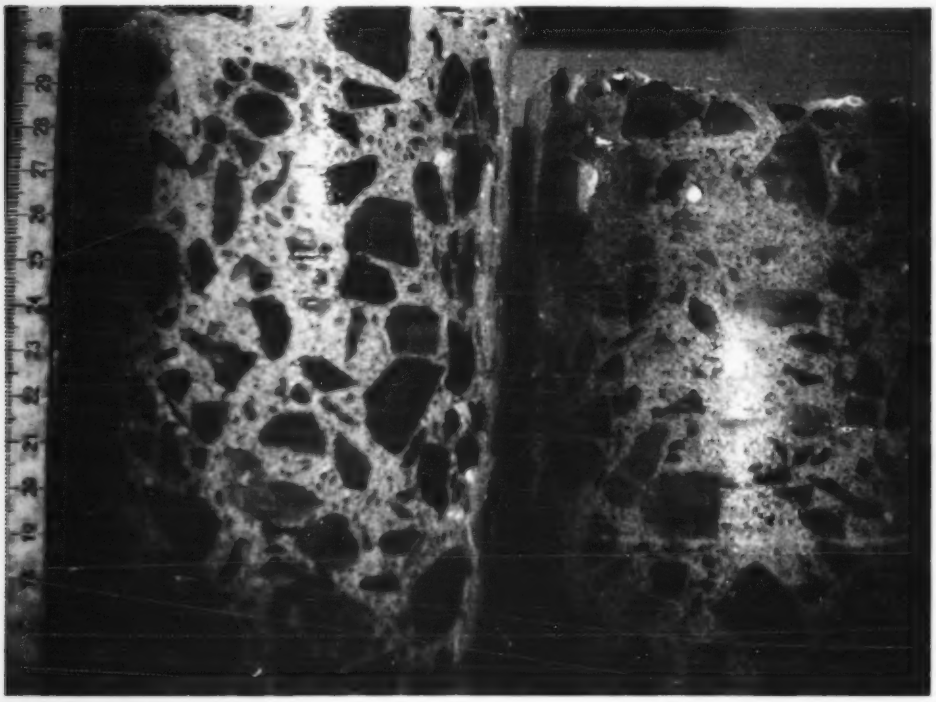

Figure 16

Location 10, Core 1

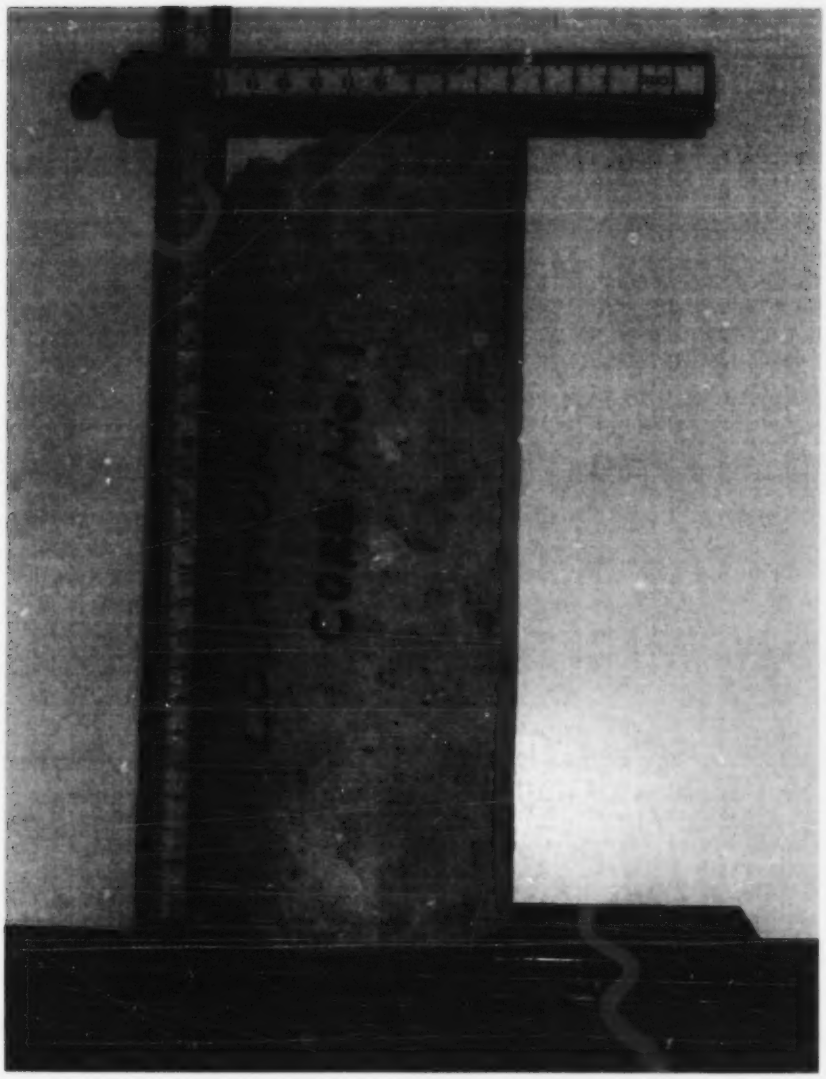

Figure 17

Location 10, Core 2

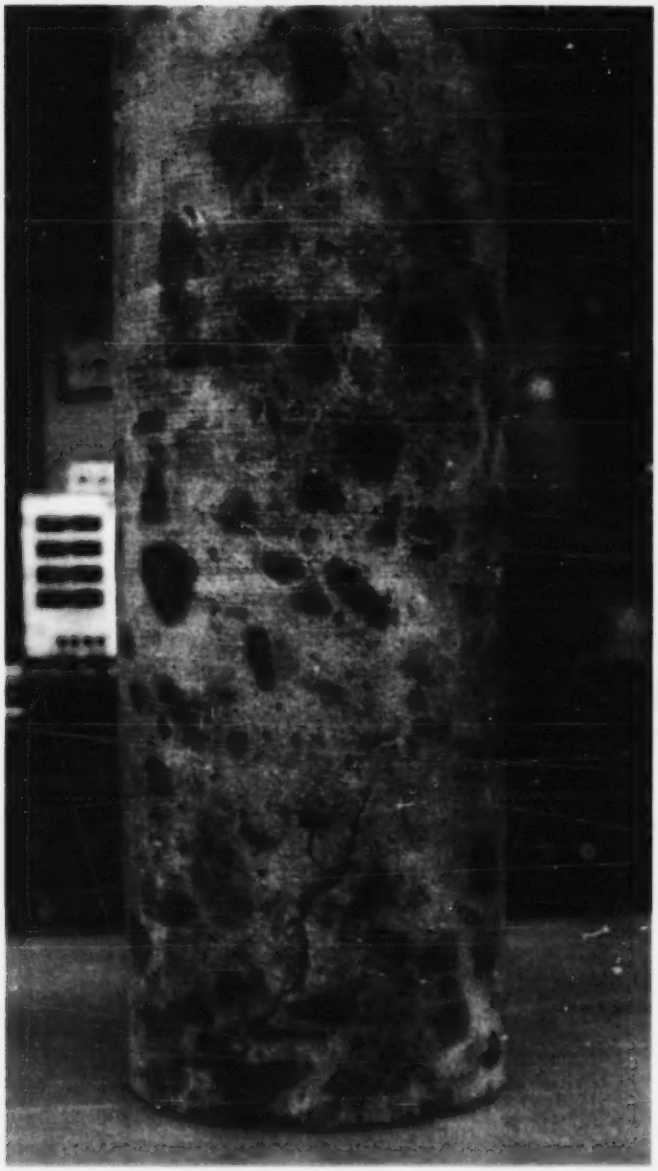

Figure 18

Location 10, Core 3

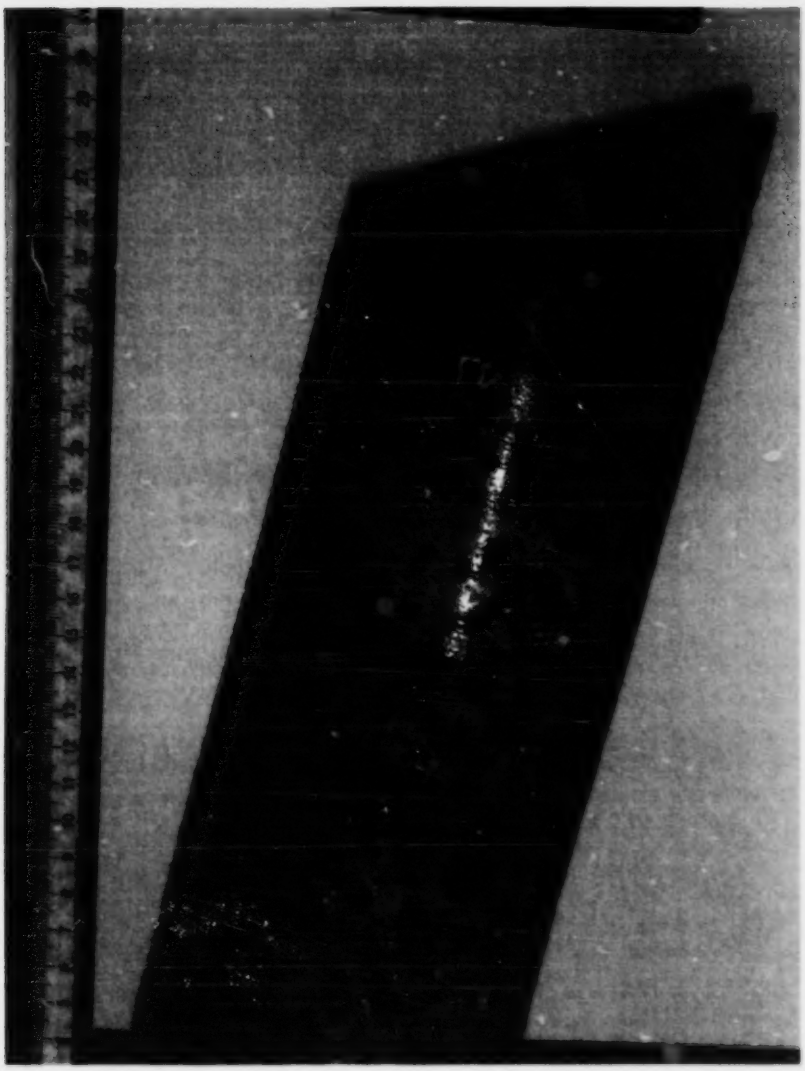

Figure 19

Location 10, Core 3

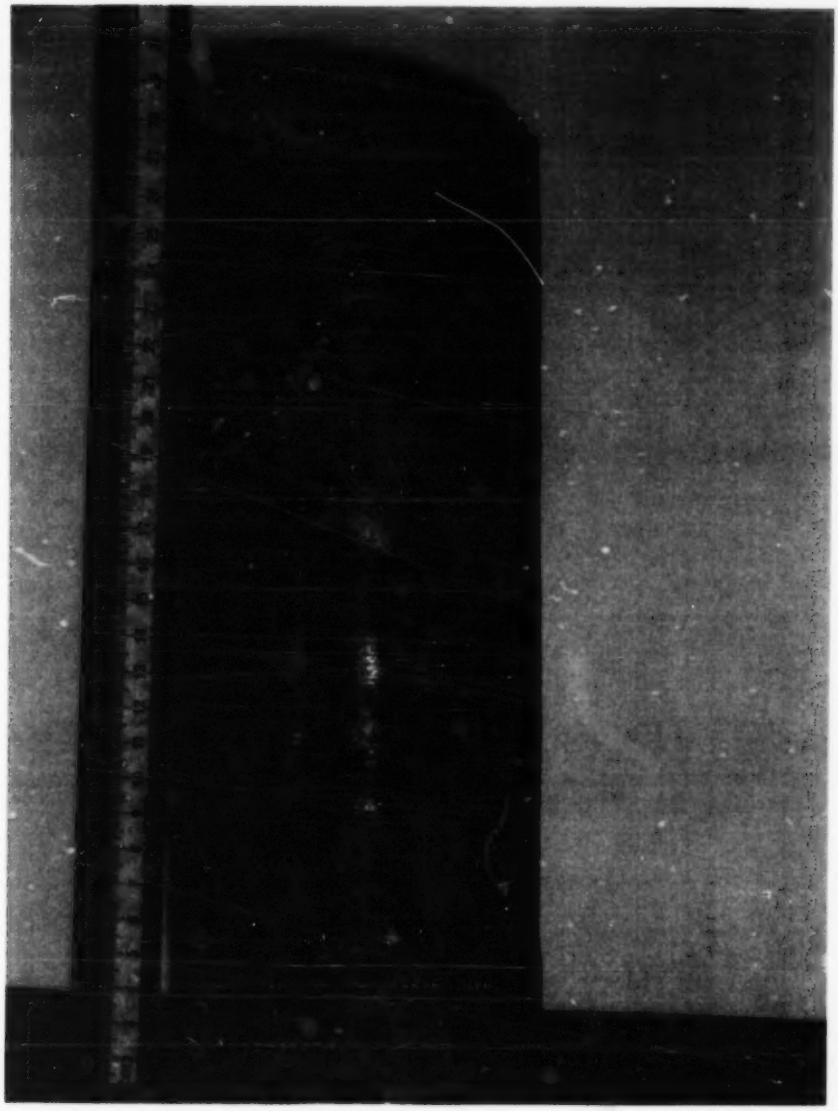

Figure 20

Staining on the Wall